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Squeeze-Film Gas Damping In a Pzt Accelerometer

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Abstract:- The model of a micro system accelerometer shows how to couple squeeze-film gas damping, which you model with the nonlinear Reynolds equation, to displacement in the sensor. This example models the solid moving parts in the accelerometer using the Solid and Structural Mechanics interface, in this study we observe the proof-mass deformation at applied different ambient pressure top and bottom face of the plates. We observe the result in 2D and 3D graphs with piezoelectric material. The presence of the piezoelectric material on the tethers changes the dynamics somewhat and reduce the maximum stress that the tether bases can be subjected to, owning to the fact that the fracture stress of PZT material are typically an order of magnitude less than that of single crystal silicon. This model solves the squeeze film air damping on the lower and upper surfaces using the Film-Damping shell interface.

Keywords:- MEMS, PZT thin film, gas damping, accelerometer

I. INTRODUCTION

An accelerometer is an electromechanical device that measures the acceleration force experienced by an object due to inertial forces or due to mechanical excitation. Nowadays, there is a huge interest in Micro Electro Mechanical Systems (MEMS) technology. Multiple sensors are often combined to provide multi-axis sensing and more accurate data [1]. Micro-accelerometers or accelerometers are one of the most important type of MEMS devices, which have the second largest scale volume after pressure sensor[2]. Generally, an accelerometer consists of either proof mass, seismic mass, or comb finger suspended by compliant beams anchored to a fixed frame. The operation can be modelled by a second-order mass-damping system. External acceleration can be measured by relative displacement (capacitance) or by suspension-beam stress. MEMS accelerometers function by detecting the deflections of the proof mass, suspended from a frame via relatively complaint tethers the deflection of the proof mass deflections may be achieved via capacitive, piezoelectric or even tunnelling current sensors, and the device are designed to operate linearly and for maximum sensitivity within the intended levels of input accelerations[3]. The air in the surrounding space is used to produce the damping effect. The structure that supports the mass acts as a spring. Most MEMS accelerometers are built on the principle of mechanical vibration. In these devices, piezoelectric and capacitive techniques are commonly used to convert the mechanical motion into an electrical signal. Piezoelectric accelerometers rely on piezoceramics (e.g. lead zirconate titanate) or single crystals (e.g. quartz, tourmaline). This model of a micro system accelerometer shows how to couple squeeze-film gas damping, and this example models the solid moving parts in the accelerometer using the Solid and structural Mechanics interface, in this study we observe the proof-mass deformation at applied different ambient pressure top and bottom face of the plates.

II. DAMPING PHENOMENON

As the proof-mass moves towards the stationary electrodes, pressure between the two layers increases developing damping forces. This pressure drives out the entrapped air between the parallel plates. On the contrary, when the proof-mass is moving away from the electrode the pressure in the gap is reduced causing surrounding air to flow into the gap. In both cases the force on the proof-mass caused by built-up pressure is always against the movement of the plate. The work done by the plate is consumed by the viscous flow of the air and transformed into heat. In other words, the air film acts as a damper and this type of damping is called squeeze film damping. The damping phenomenon is shown in fig.1

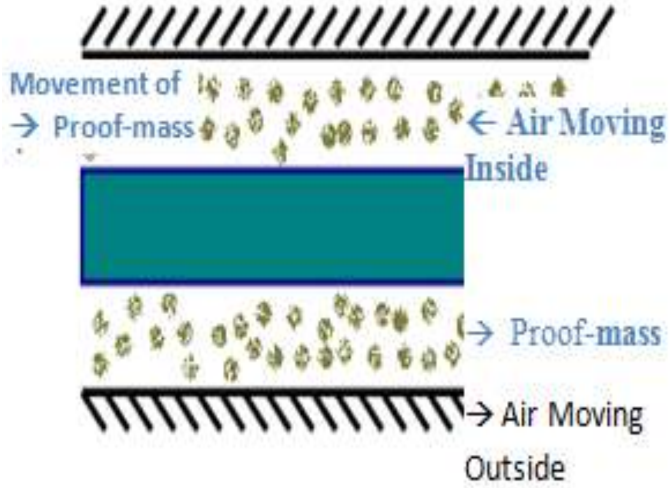

Fig.1 Damping phenomenon

III. COMSOL MODEL

The use of COMSOL Multiphysics with a simple correlation of COMSOL geometry models to physical data. The purpose is twofold: first, it allows a control on experiments by ensuring proper extraction of material properties from our test structure data. Second, it helps to ensure that modelling complex design geometrics in COMSOL yields practical and unable data that allows MEMS designers to build meaningful predictions. Nano~material composites in MEMS fabrication have material properties that are either nonexistent or poorly characterized in present literature. Investigating stationary structural mechanics and Young's modules (E) in particular in carbon-carbon composites is an initial effort to understand the mechanical fundamentals. COMSOL helps validate that the method used to distil Young's modules from physical test structures is reasonable. After calculating Young's modulus from test structure data using beam theory, that values of E is entered into the COMSOL model of that structure to make certain that the modelled deflections in COMSOL is reasonably close to the deflection expected from AFM force versus deflection curves.

MODEL GEOMETRY

This example models the solid moving parts in the accelerometer using the Solid Mechanics interface in 3D and using the solid mechanics interface with a plane strain approximation in 2D.This model solves the squeeze film air damping on the lower and upper surfaces using the Film-Damping shell interface. The model constrains the film pressure,p_f, to 0 at the edges of the boundary. The model consists of two thin PZT-5H cantilever beams and a silicon proof mass. The cantilever beams are fixed to the surrounding structures at one end. The proof mass reacts to inertial forces and bends the cantilevers. The external acceleration, α, acts in the z direction and causes a body volume force$F_z = \rho^{\alpha}_{solid}$.

In 2D two cantilevers are lumped as one structure whose thickness equals to the sum of the thickness of two cantilevers. Consequentially, the model has two domains with different thickness as the connecting boundary. You should therefore be prudent with inspecting stress level near this area.

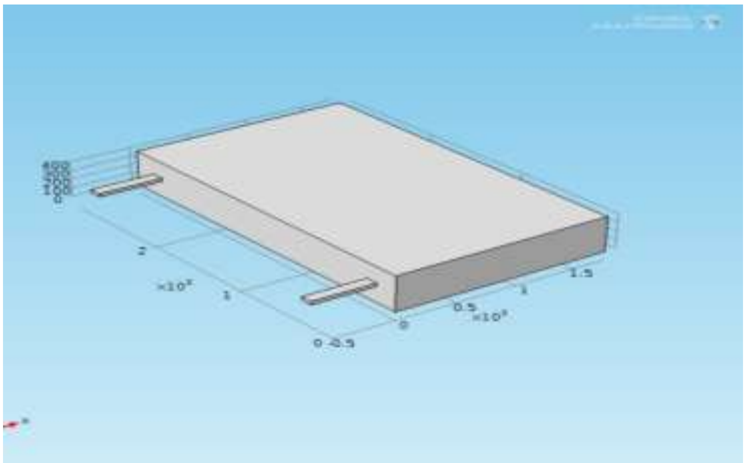

Figure 2: Model geometry in 3D.

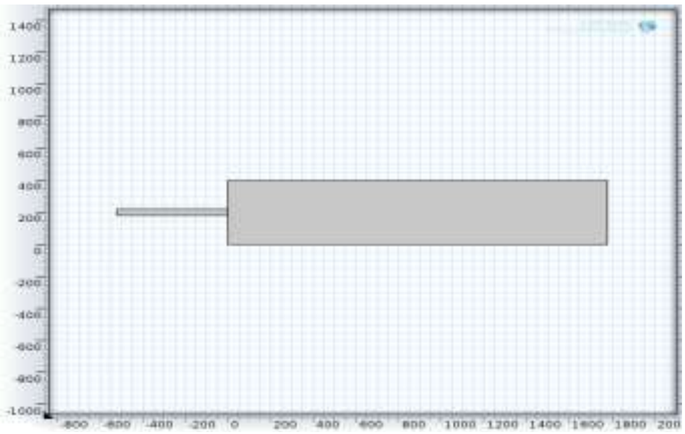

Figure 3: Model geometry in 2D

The following tables list the structures' dimensions as well as pertinent material and gas properties used to calculate the effective viscosity:

Parameters	Cantilevers	Proof mass	Gap
Length	**520µm**	**1780 µm**	**1780 µm**
Height	**40 µm**	**400 µm**	**3.95 µm**
Width	**100 µm**	**2960 µm**	**2960 µm**

Parameter	Value
Structural material	**PZT-5H**
Young's modulus	**153.9 GPa**
Poisson's ratio	**0.31**
Density	**2330kg/m^3**
Viscosity of the gas	**22.6.10^{-6} Ns/m^2**
$\boldsymbol{\lambda_0}$	**70 nm**
$\boldsymbol{p_0}$	**101.325 kPa**

IV. SQUEEZE –FILM GAS DAMPING

Squeeze-film gas damping is a critical aspect of many MEMS transducers and actuators. An example of a micro system component where gas-damping properties are important is an accelerometer common in vehicle motion-control and safety systems. In accelerometers, inertia produces a motion that the device detects.

A typical structure connects a large proof mass, with dimensions typically in millimetres, to surrounding structures with elastic beams. This combination forms a mechanical oscillator with a specific resonance frequency. However, in accurate motion-detection applications these resonances are unwanted, and the device damps the movements to produce smooth time-step and frequency responses. Such a device can usually achieve suitable damping with a low gas pressure (100 Pa–1000 Pa) that, considering the dimensions of the device, leads to rarefied gas effect in the system[6]

A narrow gap formed by two solid horizontal plates restricts the displacement of the gas perpendicular to the surfaces. When the sensor squeezes the gap, the gas flows out from its edges. The narrow pathway restricts the flow, which causes gas pressure to increase. This increase in gas pressure, in turn, decelerates the plates' movement. In this model the pressure distribution in the narrow gap with the modified Reynolds's equation.

$$\frac{d}{dt}(ph) + \nabla_t.(phu) - p((\nabla_t h_s.u_s) - \nabla_t h_b.u_b)) = 0$$

where the total fluid pressure p is the sum of the initial/ambient pressure, pA and the variation pf; $h = h_0 + \nabla h(t)$ is the gap height consisting of the initial gap and the deformation in the normal direction of the boundary; h_s is the location of the solid wall; h_b is the location of the channel base; and u_s and u_b define the tangential velocity of the solid and the channel base, respectively. Furthermore, the mean film velocity u is given by

$$u = -\frac{\nabla_t p}{12\eta}h^2 Q_{ch} + \frac{(u_s + u_b)}{2}$$

Where η denotes the fluid viscosity at normal condition and the term Q_{ch} is the relative flow rate function that accounts for the rarefied gas effects. Veijola and others [7] have used a simple equation for the relative flow coefficient

$$Q_{ch} = 1 + 9.638(\sigma_p K_n)^{1.159}$$

Which is valid for $0 \leq K_n \leq 880$.The Knudsen number is the ratio between the gas mean free path,λ,and the gap height.h:

$$K_n = \frac{\lambda}{h}$$

The coefficient σ_p is calculated from the tangential momentum accommodation coefficient,α_v:

$$\sigma_p = \frac{2-\alpha_v}{\alpha_v}(1.016 - 0.1211(1-\alpha_v))$$

The mean free path at a pressure p comes from

$$\lambda = \frac{p_0}{p}\lambda_0$$

Where λ_0 is the mean free path at the reference pressurep_0.

Another way to tune the damping is to perforate the structure with holes. By adding a term related to the gas flow through the holes , it is also possible to use the Reynolds equation for perforated plates. For more information about this approach[8].

V. RESULTS AND DISCUSSION

In figure 6. Shows, the pressure distribution on the surface of the proof mass after 4ms of simulation. The ambient pressure, pA, and the acceleration switches on at the beginning of the simulation. The acceleration's magnitude is half that due to gravity, g. In this figure, the maximum displacement at the tip of the proof mass is roughly 0.2µm,or 0.05% of its thickness.

In figure 8. Shows, the z displacement of the proof mass tip as a function of time for ambient pressure of 10pA, 500pA , 600pA and 700pA. As ambient pressure increases the film damping at the upper and lower surface increases through the increase in the gas effective viscosity and density. This increased damping results in a substantial decrease in oscillation with increasing pressure. At 500 pA , there is no apparent oscillation, and the proof mass seems asymptotically reacting the value of 0.2 µm in a displacement.

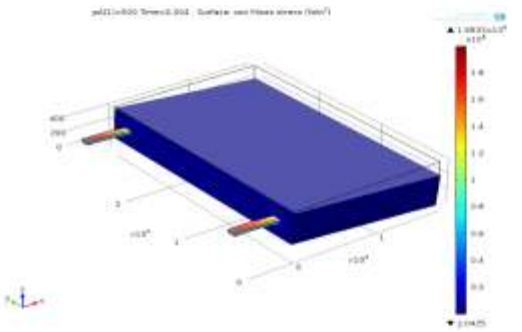

Figure 4: stress distribution in 3D

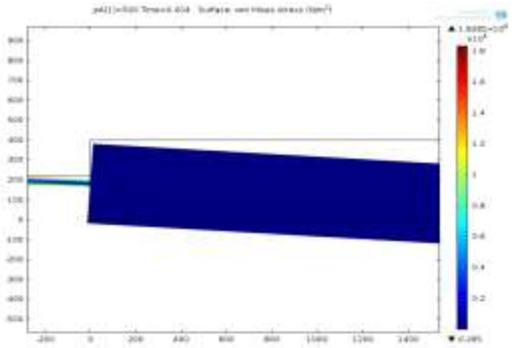

Figure 5: stress distribution in 2D

Figure 6: Shows a load on the face of the proof mass in the Z direction deformation at applied different ambient pressure in 3D model.

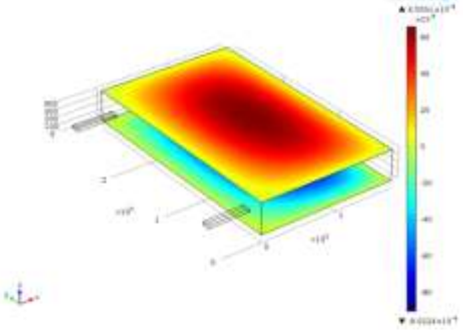

Figure 6(a): A load on the face of the proof mass in the Z direction leads to a deformation at applied 10 Pa ambient pressure.

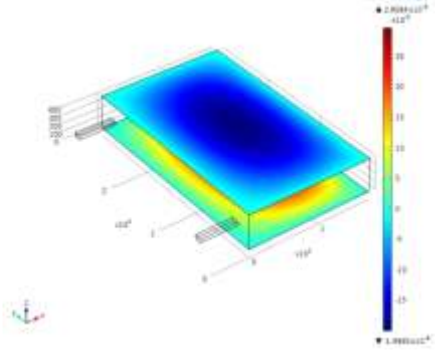

Figure 6(b): A load on the face of the proof in the Z direction leads to a deformation at applied 500 Pa ambient pressure.

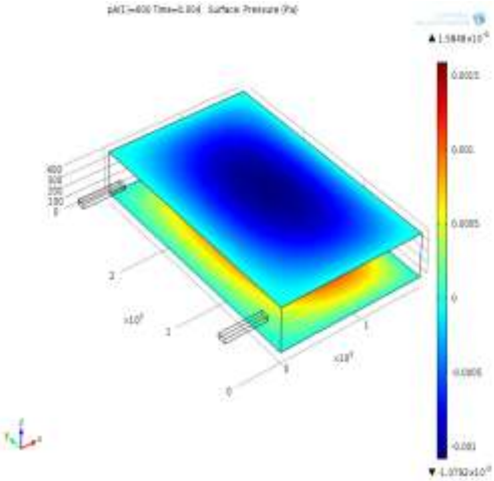

Figure 6(c): A load on the face of the proof mass in the Z direction leads to a deformation at applied 600 Pa ambient pressure.

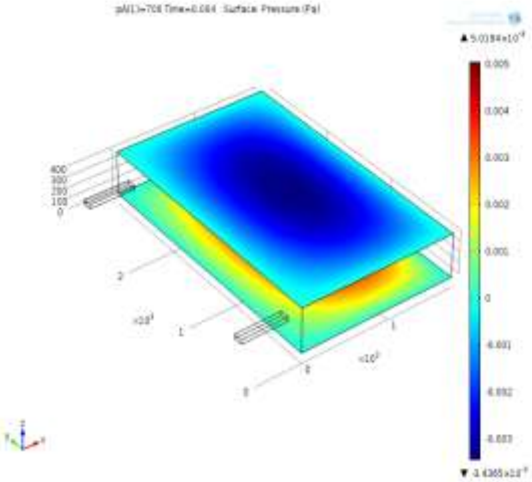

Figure 6(d): A load on the face of the proof in the Z direction leads to a deformation at applied 700 Pa ambient pressure.

Figure 7: Shows the mass deformation in 2D model.

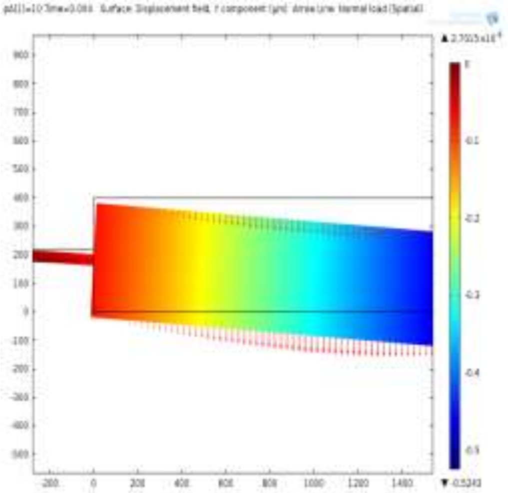

Figure 7(a): A load on the proof mass on the Top face Appling 10 Pa

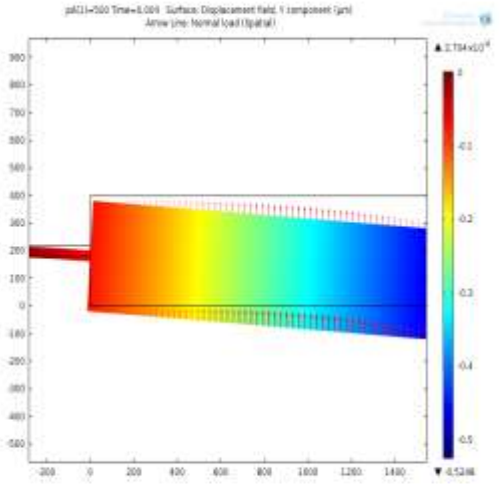

Figure 7(b): A load on the proof mass on the Top face Appling 500 Pa

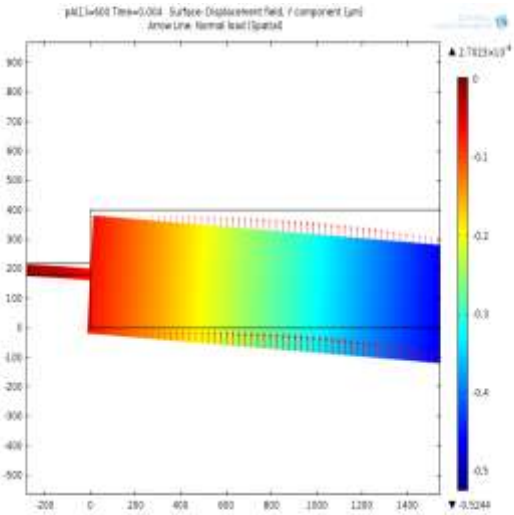

Figure 7(c): A load on the proof mass on the Top face Appling 600 Pa

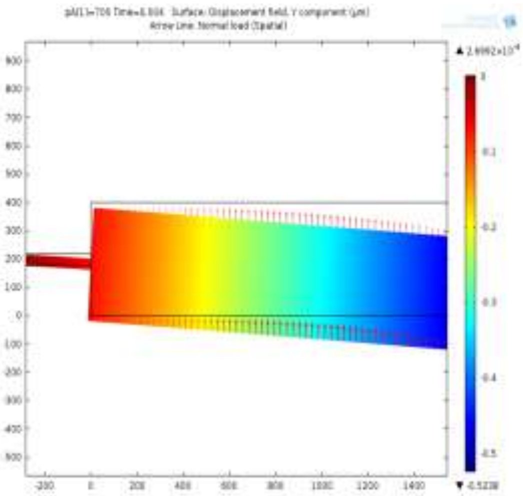

Figure 7(d): A load on the proof mass on the Top face Appling 700 Pa

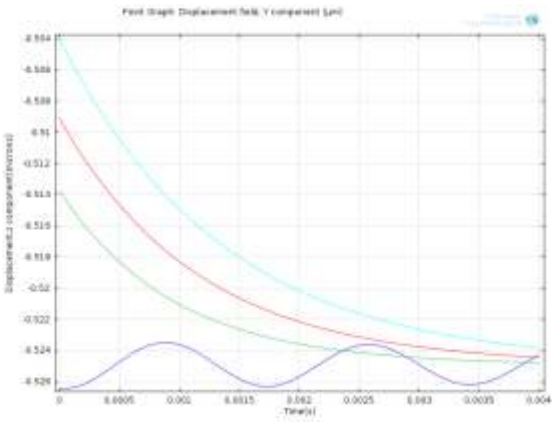

Figure 8: The displacement of the proof mass tip at ambient pressure of 10 Pa, 500 Pa, 600 Pa, and 700 Pa.

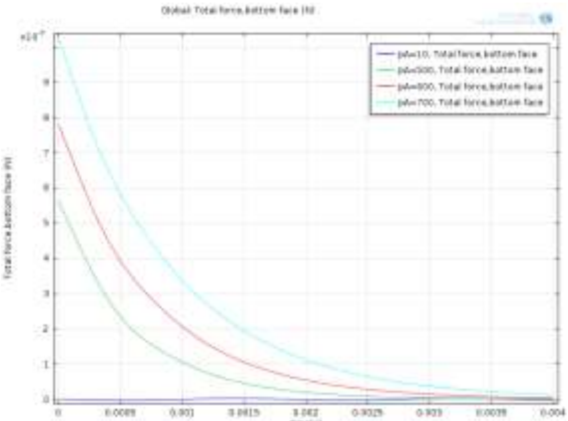

figure 9:The load on the bottom face versus time for different ambient pressure values.

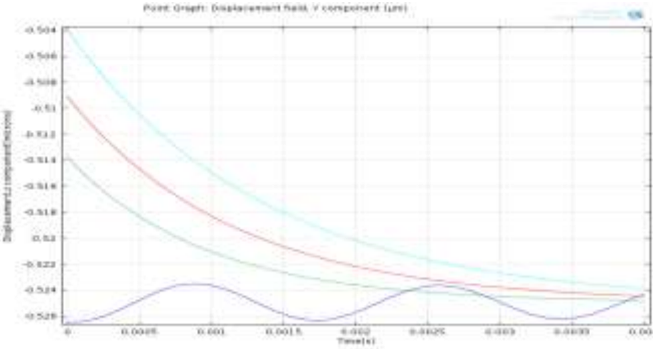

Figure 10: Vertical displacement of the proof mass tip versus time for different ambient pressure values.

VI. CONCLUSION

We model the squeeze film gas damping PZT accelerometers, aimed at determining the material and geometry limitations on the structural integrity of the device. COMSOL multiphysics is used through this simulation study, the relationship of the geometry and material to the resonance mode, and we appling the different ambient pressure in top and bottom of the surfacess and we observe the proof-mass deformation and large deflection dynamics of the tethers and the corsponding displacement-sterss relation ship. squeeze film gas damping is the important issue in the desigining of MEMS devices.

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REFERENCES

[1]. B. S. Sreeja and S. Radha, "design and implementation of MEMS based differential voltage controlled oscillator ", In proceedings of EIT "2009, Windsor, Canada, 2009, pp.202-206.

[2]. B. Liu, Q. Yao and B. Kriegbaum, "Finite element based design and optimization for piezoelectric accelerometers ", Proceeding for Inter-Noice 98, Christchurch, New Zealand, 1998.

[3]. L.P Wang, , R.A. Wolf, Jr., Y. Wang, K. K. DENG, L, Zou, R.J. davis, and S. Trolier-Mckinstry, "design, Fabrication, and Measurement o High-Sensitivity Piezoelectric Micromechanical Systems Accelerometers", Journal of Micromechanical Systems, Vol. 12, No. 4, August 2003, pp.433-440.

[4]. J.B.Starr,"Squeeze –film Damping in solid –state Accelerometers," Technical design IEEE Solid-state Sensor and Actuator workshop,p.47,1990.

[5]. TVeijola,H.Kuisma.J.Lahdenpera,and T.Ryhanen, "Equivalent-circuit model of the squeezed Gas film in a silicon Accelerometers ," sensors and actuators, A 48, pp.239-248, 1995.

[6]. M. Bao, H. Yang, Y. Sun, and P.J. French, "Modified Reynolds' equation and Analytical Analysis of Squeeze-film Air damping of Perforated Structures," J. Micromech. Microeng., vol. 13, pp. 795-800, 2003.